AN IMPROVED ENERGY EFFICIENT MEDIUM ACCESS CONTROL PROTOCOL FOR WIRELESS SENSOR NETWORKS

K. P. Sampoornam[1], K. Rameshwaran[2]
[1]Department of ECE, K.S.R. College of Engg., Tiruchengode ,Tamil Nadu, India.
[2]Principal, JJ College of Engg., Tiruchirappalli, Tamil Nadu, India.

ABSTRACT

Wireless Sensor Networks (WSN) constitute a special class of wireless data communication networks. In wireless sensor networks, sensor nodes are randomly deployed. Since the sensor nodes are required to operate under remote conditions without fresh supply of power to replenish itself, energy conservation becomes the major constraint. This necessitates the design of WSNs with the capability of prolonging the lifetime of network. To achieve minimum energy consumption, several MAC protocols have already proposed. This paper aims to survey and analyze the most energy efficient medium access control protocols and to compare their performances. Further, this paper proposes a new MAC protocol based on Orthogonal Frequency Division Multiplexing (OFDM).In ELE-MAC protocol, by employing OFDMA the energy consumption of the node can be minimized.

KEYWORDS: *Wireless Sensor Networks, Media Access Control, Energy, Sensor MAC, Orthogonal Frequency Division Multiplexing.*

I. INTRODUCTION

Wireless *ad hoc* sensor network is an emerging technology that promises a great potential for both military and civilian applications. Such a network can be used to monitor environment, detect, classify, and locate objects and then track them over a specified region.
The sensor network is expected to deploy varying number of sensor nodes that can sense the environment using different modalities such as acoustic, seismic, and infrared. The sensors also have the capability to communicate and interact with neighboring sensors via wireless channels and also they are able of processing the information. It is expected that these components can be integrated into a tightly packed, low cost sensor nodes ready for massive deployment.
For military applications, these low-cost, integrated wireless sensor nodes can be rapidly deployed by air over remote regions to monitor vehicles and personnel movements and to relay the findings back to the command center on a real-time basis.
Research and Development on sensor networks relies on many concepts and protocols from distributed computer networks, such as Internet. However, several technical challenges in sensor networks need to be addressed due to the specialized nature of the sensors and the very fact that many sensor network applications may involve remote mobile sensors with limited power sources that must dynamically adapt to their varying environment. As the field of communication networks continues to evolve, a very interesting and challenging area of WSN is rapidly coming of age.
The basic issue in communication networks is the transmission of messages to achieve a prescribed message throughput (Quantity of Service) and Quality of Service (QoS). QoS can be specified in terms of message delay, message due dates, bit error rates, packet loss, economic cost of transmission,

transmission power, etc. This necessitates suitable MAC protocol to transmit packets over a shared channel.

1.1 Issues in Medium Access Scheme

The primary responsibility of a MAC protocol in WSN is the distributed arbitration[1]for the shared channel for transmission of packets. The major issues to be considered in designing a MAC protocol for WSNs are as follows.

1.1.1 Distributed Operation

WSNs need to operate in environments where no centralized coordination is possible. MAC protocol design should be fully distributed involving minimum control overhead.

1.1.2 Synchronization

Time synchronization is needed for TDMA based systems to manage transmission and reception slots. It involves usage of scarce sources such as bandwidth and battery power.

1.1.3 Hidden Terminals

MAC protocol should be able to alleviate the effects of hidden terminals. In addition to the above said issues, MAC protocol is to be designed in such a way that it should minimize the access delay and maximize the throughput.

The remainder of the presentation is organized as follows. In section 2, we provide a review of the related work. Section 3 discusses various existing MAC protocols. A new energy efficient multiple access scheme is proposed in section 4.Simulation results of various MAC protocols are given in section 5. Section 6 concludes the paper.

II. RELATED WORK

When multiple nodes desire to transmit, protocols are needed to avoid collisions and data loss. In the 1970's at the University of Hawaii, ALOHA scheme was first used. In this ALOHA scheme, a node simply transmits a message when it desires [1]. If it receives an acknowledgement, all is well. If not, the node waits for a random time and retransmits the message. However, its simplicity comes at an expense of very high probability of a packet collision. It increases the energy expenditure due to packet retransmission. Therefore, Carrier Sense Multiple Access (CSMA) protocol was developed [2] with the objective of minimizing collision by implementing a small time for channel listening in order to detect channel activity. However, the protocol cannot solve the hidden terminal problem which normally occurs in ad-hoc networks where the radio range is not large enough to allow communication between arbitrary nodes. Further, two or more nodes may share a common neighbor while being out of each other's reach. The MAC protocol introduces a three-way handshake mechanism to make hidden nodes aware of upcoming transmission from neighboring nodes and hence collision may be avoided. However, the handshaking mechanism causes overhead on control packets.

In Frequency Division Multiple Access (FDMA), different nodes have different carrier frequencies. Since, the frequency resources are divided, the bandwidth available for each node decreases [3]. FDMA also requires additional hardware and intelligence at each node.

In Code Division Multiple Access (CDMA), a unique code is used by each node to encode its messages. This increases the complexity of the transmitter and the receiver.

In Time Division Multiple Access (TDMA), the RF link is divided on a time axis with each node being given a predetermined time slot that can be used for communication. This decreases the sweep rate, but a major advantage is that TDMA can be implemented in software. All nodes require accurate, synchronized clocks for TDMA. Meanwhile, software power management techniques can greatly decrease the power consumed by RF sensor nodes. TDMA is especially useful for power conservation, since a node can power down or 'sleep' between its assigned time slots, waking up in time to receive and transmit messages [4]. The required transmission power increases as the square of the distance between source and destination.

Therefore, multiple short message transmission hops require less power than one long hop. In fact, if the distance between source and destination is R, the power required for single-hop transmission is proportional to R^2. If nodes between source and destination are taken advantage of, to transmit *n* short hops instead, the power required by each node is proportional to R^2/n^2. This is a strong argument in favor of distributed networks with multiple nodes, *i.e.* nets of the mesh variety.All these protocols require all nodes to continuously listen to the channel due to unpredictable packet transmission by its neighboring nodes.

III. MULTIPLE ACCESS PROTOCOLS

Media Access Control (MAC) layer manages the medium accessibility to minimize collision among transmitting packets. Packet collision requires node to retransmit the packet and hence consumes additional energy. MAC layer controls the physical layer (radio transceiver) which has greater effect on the overall energy consumption and lifetime of a node.

3.1 Energy Efficient MAC Protocols

If all nodes continuously listen to the channel due to unpredictable packet transmission by its neighboring nodes, hence introducing a problem called idle listening [5]. This situation causes a node to waste energy unnecessarily and thus making the implementation of these protocols in Wireless Sensor Networks inefficient.

3.1.1 Sensor MAC Protocols (SMAC)

This protocol solves the idle listening problem by introducing an active sleep cycle. Locally managed synchronization and periodic sleep listen schedules based on these synchronizations form the basic idea behind the Sensor MAC protocol [6]. Neighboring nodes form virtual clusters so as to set up a common sleep schedule. If two neighboring nodes reside in two different virtual clusters, they wake up at the listen periods of both clusters.

Periodic sleep may result in high latency, especially for multi-hop routing algorithms, since all intermediate nodes have their own sleep schedules [7]. The latency caused by periodic sleeping is called sleep delay. Another drawback of this protocol is sleep and listen periods are predefined and constant, which decreases the efficiency of the algorithm under variable traffic load.

3.1.2 Adaptive SMAC Protocols (ASMAC)

The great energy cost associated with idle time and overhearing suggests that optimizations must turn off the radio not simply reduce packet transmission and reception. This protocol reduces the listen time by putting nodes into periodic sleep state. Each node sleeps for predefined time and then wakes up and listens to see if any other node wants to talk to it. During sleeping, the node turns off its radio and sets a timer to wake it up later.

All nodes are free to choose their own listen-sleep schedules. In order to reduce control overhead, neighboring nodes are synchronized together. That is, they listen at the same time and go to sleep at the same time. In ASMAC, nodes coordinate their sleep schedules rather than randomly sleep on their own. This protocol also presents a technique to reduce latency due to periodic sleep on their own. This protocol also presents a technique to reduce latency due to periodic sleep on each node.

Before each node starts its periodic listen and sleep, it needs to choose its schedule and exchange it with the neighbors [8]. Each node maintains a schedule table that stores the schedule of all its known neighbors.

3.1.3 Energy Latency Efficient MAC Protocols (ELE-MAC)

The basic idea of this protocol is to minimize the control packets exchanged in the ASMAC protocol. At the same time, ELE-MAC should conserve the SMAC's benefits. Here personalized Request to Send (RTS) packet is adopted. Further, this packet provides two additional fields called Acknowledgement destination node address and Acknowledgement flag [8]. This added fields allow the new RTS packet to play the role of an ACK and RTS same time. This new packet will be exchanged only when data are sent adaptively. Thus, no ACK packet will be emitted in that case. Else-where, the transmission is performed normally. In other words, each data packet received is followed by an ACK to the sender.

In this protocol, adaptive wake up period starts immediately after receiving the data packet instead of waiting for the ACK packet like ASMAC protocol. This modification is made for allowing a receiver to inform its neighbors about the data reception through the ACK flag field. Also, this packet allows the receiver to mention its need to transmit the received packet to the next hop, if it exists.

ELE-MAC does not propose a fragmentation mechanism, like SMAC. It broadcasts packets only when virtual and physical carrier sense indicates that the medium is free[9]. In addition, these packets will not be preceded RTS/CTS and will not be acknowledged by their recipients.

IV. PROPOSED SCHEME

In order to satisfy the design requirements of WSN, a new Multiple Access based scheme called Orthogonal Frequency-Division Multiplexing (OFDM) is used along with ELE-MAC.

OFDM is essentially identical to Coded OFDM (COFDM), It is a digital multi-carrier modulation scheme that uses a large number of closely-spaced orthogonal sub-carriers to carry data. These sub-carriers typically overlap in frequency but are designed not to interfere with each other as would be the case with traditional FDM. This may be efficiently separated using a Fast Fourier Transform (FFT) algorithm [10]. Each subcarrier is modulated with a conventional modulation scheme (such as quadrature amplitude modulation) at a low symbol rate maintaining data rates similar to conventional single-carrier modulation schemes in the same bandwidth.

The primary advantage of OFDM over single-carrier schemes is its ability to cope with severe channel conditions .For example, attenuation of high frequencies in a long copper wire, narrow band interference and frequency-selective fading due to multipath without complex equalization filters. Channel equalization is simplified because OFDM may be viewed as using many slowly-modulated narrow band signals rather than one rapidly-modulated wide band signal. The low symbol rate makes the use of a guard interval between symbols affordable, making it possible to handle time-spreading and eliminate Inter Symbol Interference (ISI).

4.1 Subcarrier Based OFDM

If we consider a multiuser subcarrier, bit and power allocation scheme, where all users transmit in all the available time slots. Our objective is to minimize the overall transmit power by allocating the subcarriers to the users and by determining the number of bits and the power level transmitted on each subcarrier based on the instantaneous fading characteristics of all users. We formulate the multiuser subcarrier, bit and power allocation problem and propose an iterative algorithm to perform the multiuser subcarrier allocation. Once the subcarrier allocation is determined, the bit and power allocation algorithm can be applied to each user on its allocated subcarriers.

4.2 Sub- Band Based OFDM

For “subcarrier-to-subcarrier” allocation algorithm, different number of bit or power may be allocated to different subcarriers; the computational complexity overhead may be too large to bear for OFDM systems with large number of subcarriers. To decrease the computational complexity overhead, sub band based bit and power allocation algorithm are developed.

4.3 Orthogonality and OFDM

If the FDM system above had been able to use a set of subcarriers that were orthogonal to each other, a higher level of spectral efficiency could have been achieved. The guard bands that were necessary to allow individual demodulation of subcarriers in an FDM system would no longer be necessary [10]. The use of orthogonal subcarriers would allow the subcarriers’ spectra to overlap, thus increasing the spectral efficiency. As long as orthogonality is maintained, it is still possible to recover the individual subcarriers’ signals despite their overlapping spectrums. If the dot product of two deterministic signals is equal to zero, then these two signals are said to be orthogonal to each other. Orthogonality can also be viewed from the standpoint of stochastic processes. If two random processes are uncorrelated, then they are orthogonal. Given the random nature of signals in a communications system, this probabilistic view of orthogonality provides an intuitive understanding of the implications of orthogonality in OFDM. Later in this article, we will discuss how OFDM is implemented in practice using the discrete Fourier transform (DFT). From a basic knowledge of signals and systems, the sinusoids of the DFT form an orthogonal basis set and a signal in the vector space of the DFT can be represented as a linear combination of the orthogonal sinusoids. One view of the DFT is that the transform essentially correlates its input signal with each of the sinusoidal basis functions. If the input signal has some energy at a certain frequency, there will be a peak in the correlation of the input signal and the basis sinusoid that is at that corresponding frequency. This transform is used at the OFDM transmitter to map an input signal onto a set of orthogonal subcarriers, i.e., the orthogonal basis functions of the DFT. Similarly, the transform is used again at the OFDM receiver to process the received subcarriers. These signals from the subcarriers are then combined to form an estimate of the source signal from the transmitter. The orthogonal and uncorrelated nature of the subcarriers is exploited in OFDM with powerful results. Since the basis functions of the DFT are uncorrelated, the correlation performed in the DFT for a given subcarrier only sees energy for that corresponding subcarrier. The energy from other subcarriers does not contribute because it is uncorrelated. This separation of signal energy is the reason that the OFDM subcarriers' spectrums can overlap without causing interference.

Orthogonal property can be mathematically represented as follows.

For Continuous Time signals:

$$\int_0^T \cos(2\pi n f0t) \times \cos(2\pi m f0t)dt = 0 \; (n \neq m) \quad \text{----------------------- (1)}$$

For Discrete Time signals:

$$\sum_{k=0}^{N-1} \cos(\frac{2\pi kn}{N}) \times \cos\left(\frac{2\pi km}{N}\right) = 0 \; (n \neq m) \quad \text{----------------------- (2)}$$

The carriers of an OFDM system are sinusoids that meet this requirement because each one is a multiple of a fundamental frequency. Each one has an integer number of cycles in the fundamental period.

V. RESULTS AND DISCUSSIONS

This section describes the performance metrics of various MAC protocols. We simulated SMAC, ASMAC and ELE-MAC using Ns-2 with the defined topologies for our scenario with three parameters i.e., number of nodes **N**, maximum transmission radius **R** and side-length of the square area **L.** Another parameter defined in the topology is its density ***d***, which is defined as the average number of neighbors per node. Then, generate a network with parameters $N = 80, R = 30m \text{ and } L = 120m$. From Figures 1 and 2, it is clear that ELE-MAC protocol consumes less energy and offer low latency delay than ASMAC and SMAC protocols.

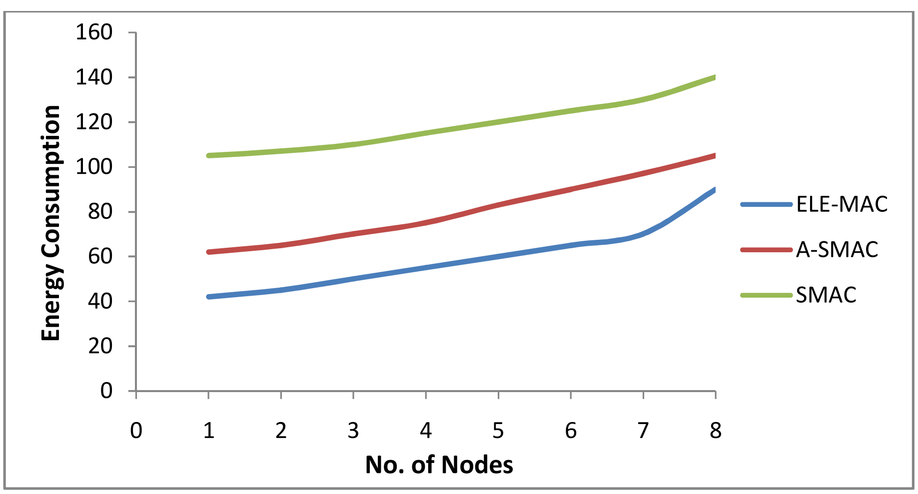

Fig.1: Energy Consumption Performance

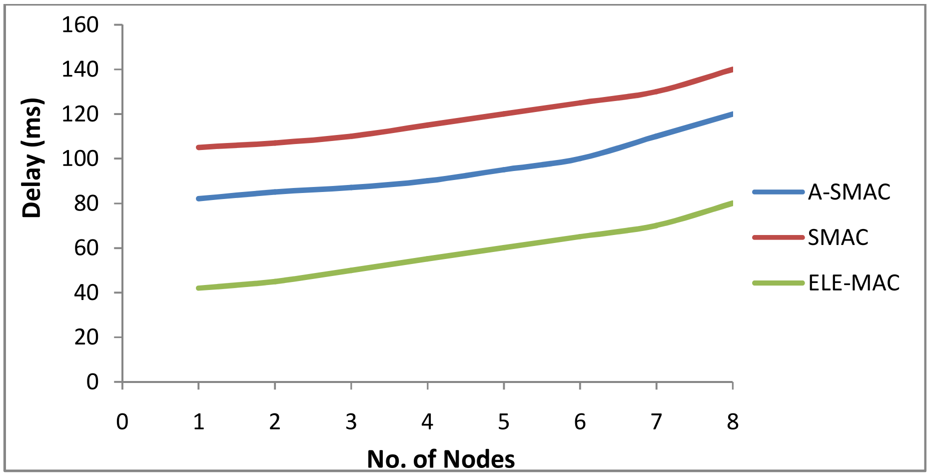

Fig.2: Energy Latency Performance

VI. CONCLUSION

This paper focuses the MAC issues in the context of minimum energy consumption and less delay in wireless sensor networks. Three energy efficient MAC protocols were studied and their performances were analyzed by implementing these MAC protocols using NS-2 simulator.

From this WSN MAC protocols survey, It has been emphasized that novel protocols and algorithms are needed to effectively tackle the application requirements of sensor networks. So, the design of optimal WSNMAC protocol is required to achieve minimum energy consumption and minimum delay. By using ELE-MAC along with OFDMA, the adjacent packets are transmitted with orthogonal nature; we may achieve better energy consumption.

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Authors

K. P. Sampoornam was born in Erode on 16th May 1969.She Received the B.E degree in Electronics and Communication Engineering from V.L.B. Janakiammal College of Engineering, Coimbatore and M.E degree in VLSI Design from Government College of Technology, Coimbatore , Tamil Nadu on 1990 and 2005 respectively. She has been doing Ph.D in Electronics Engineering under Anna University of Technology, Coimbatore in part time. She worked as a lecturer in ECE department in Al-Ameen Polytecnic College from 1993 to 1997.Then she worked as a lecturer in ECE department in MPNMJ Polytechnic College & MPNMJ Engineering College from 1997-2007.After that she worked as an Assistant professor in ECE department from 2007 to 2009 and an Associate professor in ECE department from 2009 to till now in K.S.R. College of Engineering, Tiruchengode, Tamil Nadu, India. She has presented a paper in National conference which was conducted by S.A. Engineering College-Chennai. Her current research interests are in the areas of wavelet analysis, watermarking, image processing and Wireless sensor networks. Ms. K. P. Sampoornam is a life member of ISTE.

K. Rameshwaran was born in Ramanathapuram, Tamilnadu on 1st June 1958. He obtained his B.E. degree in Electronics & Communication Engineering from the University of Madras in 1980. He obtained his M.E.degree in Electronics Engineering from Anna University, Chennai in 1982 and his Ph.D. degree from I.I.T.Madras, Chennai. He started his professional career with a brief stint at I.I.T. Madras during 1982-1983 as a Project Engineer. He joined the department of Electrical Engineering at the Thiagarajar College of Engineering, Madurai as an Associate Lecturer in July 1983. Later, he joined the department of Electronics and Communication Engineering at the erstwhile Regional Engineering College (Presently known as National Institute of Technology), Tiruchirappalli in 1987. During the period between July 2006 and June 2008, he worked as the Principal of K.S.R. College of Engineering, Tiruchengode in Namakkal(District), Tamilnadu. Consequent to his retirement on Voluntary basis (VRS) from NITT in December 2009, he joined as the Principal of R.M.K. Engineering College, Kavaraipettai-601 206 and worked for a brief period of 7 (Seven) months. Now he has been working as the principle of JJ College of Engineering and Technology, Ammapettai, Tiruchirappalli-620 009. He has published several research papers in International and National Journals. He has also presented research papers in National and International conferences. His areas of interest are: Digital system and Microprocessors, Digital Filters and Control theory.